Enhancement technology improves palatability of normal and callipyge lambs

A. K. R. Everts, D. M. Wulf, T. L. Wheeler, A. J. Everts, A. D. Weaver and J. A. Daniel

J Anim Sci 2010.88:4026-4036.
doi: 10.2527/jas.2010-2845 originally published online Jul 30, 2010;

Enhancement technology improves palatability of normal and callipyge lambs

A. K. R. Everts,* D. M. Wulf,* T. L. Wheeler,† A. J. Everts,* A. D. Weaver,*[1] and J. A. Daniel*

*South Dakota State University, Brookings 57007;
and †USDA, ARS, US Meat Animal Research Center, Clay Center, NE 68933

ABSTRACT: The objective of this research was to determine if BPI Processing Technology (BPT) improved palatability of normal (NN) and callipyge (CN) lamb meat and to determine the mechanism by which palatability was improved. Ten ewe and 10 wether lambs of each phenotype were slaughtered, and carcass traits were assessed by a trained evaluator. The LM was removed at 2 d postmortem. Alternating sides served as controls (CON) or were treated with BPT. Muscles designated BPT were injected to a target 120% by weight with a patented solution containing water, ammonium hydroxide, carbon monoxide, and salt. Muscle pH, cooking loss, Warner-Bratzler shear force (WBS), sarcomere length, cooked moisture retention, and desmin degradation were measured. A trained sensory panel and a take-home consumer panel evaluated LM chops. Callipyge had a heavier BW and HCW, less adjusted fat thickness, reduced yield grades, and greater conformation scores than NN ($P < 0.05$). For LM, NN had shorter sarcomeres, smaller WBS values, greater juiciness ratings, more off-flavors, reduced consumer ratings for raw characteristics (like of portion size, like of color, like of leanness, overall like of appearance) and greater consumer ratings for eating characteristics (like of juiciness, like of flavor) than CN ($P < 0.05$). For LM, BPT had greater cooked moisture retention, smaller WBS values, greater juiciness ratings, less off-flavors, and greater consumer ratings for raw characteristics (like of portion size, like of color, overall like of appearance) and eating characteristics (like of juiciness, like of flavor) than CON ($P < 0.05$). Significant phenotype × treatment interactions occurred for LM muscle pH, desmin degradation, tenderness, consumer like of texture/tenderness, and consumer overall like of eating quality ($P < 0.05$). For LM, BPT increased muscle pH more for NN than CN ($P < 0.01$) and increased desmin degradation for NN but decreased desmin degradation for CN ($P < 0.01$). The BPT enhancement improved LM tenderness ratings for CN more than NN ($P < 0.05$). For consumer like of texture/tenderness, BPT improved ratings for CN more than NN ($P < 0.01$). For consumer overall like of eating quality, BPT improved ratings for CN more than NN ($P < 0.05$). In summary, BPT had little to no effect on sarcomere length and desmin degradation, but improved palatability of NN and CN lamb by increasing cooked moisture retention, improving consumer acceptability of CN to near-normal levels.

Key words: callipyge, enhancement, lamb, palatability, proteolysis, tenderness

J. Anim. Sci. 2010. 88:4026–4036
doi:10.2527/jas.2010-2845

INTRODUCTION

Callipyge lambs demonstrate increased feed efficiency, muscle mass, and weight of lean product, without increasing the risk of dystocia at birth (Jackson et al., 1997a,b), appealing characteristics to both producers and packers. However, callipyge lambs produce inherently tough meat, especially the LM, when compared with normal lamb (Koohmaraie et al., 1995, 1998; Shackelford et al., 1997).

Past work has shown consumers prefer the leanness and size of callipyge cuts compared with normal lamb cuts (Carpenter et al., 1997); however, consumers have indicated callipyge chops are tough and dry (Moore et al., 1998). Various methods have been utilized to improve palatability of callipyge meat including electrical stimulation (Carpenter et al., 1997; Leckie et al., 1997; Kerth et al., 1999), calcium chloride injection (Koohmaraie et al., 1988, 1998; Carpenter et al., 1997), sarcomere lengthening (Koohmaraie et al., 1998), and vitamin D_3 supplementation (Wiegand et al., 2001).

The BPI Processing Technology is a patented meat enhancement process that injects meat with a solution of water, ammonium hydroxide, carbon monoxide, and

[1]Corresponding author: amanda.weaver@sdstate.edu
Received January 20, 2010.
Accepted July 23, 2010.

salt. This solution has a brine pH of approximately 11 and increases muscle pH to a range of 5.9 to 6.3 in beef steaks (Hand et al., 2005). Ammonium hydroxide is a GRAS (generally recognized as safe) ingredient (USDA, 2001). As pH moves farther away from the isoelectric point, more water molecules are able to bind, resulting in increased water-holding capacity. Previous work has shown that consumers prefer pH-enhanced beef steaks to control beef steaks. Also, BPI Processing Technology (**BPT**; Freezing Machines Inc., Dakota Dunes, SD)-beef steaks have improved tenderness, juiciness, and beef flavor ratings compared with control beef steaks (Hand et al., 2005; Nath, 2006). However, the effect of BPT has not been tested with either normal or callipyge lamb. The objectives of this study were to determine if 1) BPT improves palatability and consumer acceptance of normal and callipyge lamb and 2) BPT alters sarcomere length, desmin degradation, and cooked moisture retention.

MATERIALS AND METHODS

Animal care and experimental protocols were not approved by the Animal Care and Use Committee because samples were collected from the state-inspected South Dakota State University Meat Laboratory.

Animals

Forty market-weight lambs of 2 known phenotypes, normal (n = 20) and callipyge (n = 20), and 2 sex classes, ewes (n = 10) and wethers (n = 10) of each phenotype, were transported from the US Meat Animal Research Center to South Dakota State University (**SDSU**) for slaughter and fabrication. Upon arrival to SDSU, lambs were allowed to rest overnight and were slaughtered the next day.

Animals were slaughtered and HCW were recorded and dressing percentages calculated. Carcasses were chilled for 48 h at 2°C. At 2 d postmortem, 12th-rib fat thickness, adjusted 12th rib fat thickness, body wall fat thickness, carcass conformation, maturity, and flank streakings were evaluated. The LM, semimembranosus (**SM**), and biceps femoris (**BF**) were excised from each side of each carcass and stored at 2°C for further analysis.

The loin and rack remained as 1 continuous bone-in cut, from the leg to the shoulder. The left and right carcass sides were separated down the center of the vertebral column, with alternating sides of the carcass randomly assigned to 1 of 2 treatments, either control or BPT-enhanced. The rhomboideus, trapezius, psoas major, and psoas minor muscles were removed; external fat was trimmed (6.4 mm), and each bone-in LM was weighed.

The SM and BF were excised from each carcass and trimmed of excess fat. The adductor muscle remained attached to the SM. For the SM and BF, treatments were assigned randomly to left and right sides, grouped and identified according to phenotype and sex (normal lamb wether, normal lamb ewe, callipyge lamb wether, and callipyge lamb ewe), without individual animal identification remaining with the muscle.

BPI Processing Technology

At 3 d postmortem, LM, SM, and BF muscles selected to be treated with BPT were transported in a refrigerated carrier to a Beef Products Inc. production facility in South Sioux City, Nebraska. Samples were weighed and injected using precision equipment modified by BPI to achieve optimal performance and using a solution containing water, ammonium hydroxide, carbon monoxide, and salt (patent held by Freezing Machines Inc., Dakota Dunes, SD) to a target injection of 20% over green weight. A 20% target injection was used as Nath (2006) found that beef LM injected above 20% with BPT resulted in some non-meat textures as indicated by trained sensory panelists. The LM was pumped as an individual piece and maintained an individual identity. For SM and BF muscles, treatment was applied to the group and muscles were weighed as a group (did not maintain individual ID). After injection, samples were weighed, and actual injection percentage was determined. Samples were then vacuum-packaged and transported back to SDSU Meat Laboratory by refrigerated carrier for further analysis.

Muscle Fabrication

Starting from the caudal end, 2.5-cm-thick LM chops were cut 1 d post-BPT enhancement (4 d postmortem), and chop assignments were as follows: chops 1 through 4 (loin chops) for trained sensory panel, chops 5 and 6 for Warner-Bratzler shear force (**WBS**), and the remaining chops (rib chops) for take-home consumer panel. After bone-in chops were cut from the LM, control and BPT ribeye area was measured on chop 6. The spinalis dorsi muscle was removed from the take-home consumer chops if a large portion was present. All chops for take-home consumer panel were randomly assigned a number, tagged accordingly, vacuum packaged, and stored at 2°C until cooking (never frozen). Shear force and trained sensory panel chops were labeled, vacuum packaged, and stored at 2°C until cooking (never frozen). Samples designated for WBS, trained sensory panel, and take-home consumer panel were never frozen because it has been shown that freezing affects WBS values (Shanks et al., 2002).

Warner-Bratzler shear force was measured on the LM 11 d post-BPT-enhanced (14 d postmortem), SM 12 d post-BPT-enhanced (15 d postmortem) and BF 13 d post-BPT-enhanced (16 d postmortem) chops, but trained sensory panel evaluation was conducted only on LM 12 and 18 d post-BPT-enhanced (15 and 21 d postmortem) and SM 5 and 10 d post-BPT-enhanced (8 and 13 d postmortem) chops. The SM was faced on the

anterior end, then cut into three 2.5-cm-thick chops; chop 1 was used for WBS and chops 2 and 3 were used for trained sensory panel.

pH and WBS Determination

Muscle pH was measured immediately before cooking on all chops assigned to WBS using a calibrated instrumental probe pH meter (MPI pH Meter, Pelican 1450, Torrance, CA). Warner-Bratzler shear force was determined according to standards set by the American Meat Science Association (AMSA, 1995). Chops were cooked on an electric clamshell grill (George Foreman Indoor/Outdoor Grill, model GGR62, Lake Forest, IL) to an internal temperature of 71°C. Each chop was weighed before and after cooking to determine cooking loss. Percent moisture retained after cooking was calculated with the following equation: (72 + injection %) − [cookloss/100 × (100 + injection %)] ÷ [(100 − cookloss)/100] × 100 = % moisture retained.

After cooking, samples were cooled to room temperature. Six 1.27-cm-diameter cores were removed from each muscle from each carcass/treatment combination and sheared perpendicular to the muscle fiber orientation on a WBS Machine (G-R Electric Manufacturing Co., Manhattan, KS). After shear force determination, cooked LM cores and the remaining cooked LM were frozen at −20°C for future sarcomere length and immunoblotting analysis.

Sarcomere Length

The LM cooked cores and remaining cooked LM from WBS were thawed and 6 cubes were fixed as described by Koolmees et al. (1986); 6 fibers per cube were measured for a total of 36 measurements per sample. Sarcomere length was determined by helium neon laser diffraction (model 05-LHR-021, Melles Groit, Carlsbad, CA) as described by Cross et al. (1981). The residual cores and cooked LM were trimmed of surface crust, powdered in liquid nitrogen, and stored at −20°C for immunoblotting.

Immunoblotting

Longissimus muscle extracts were prepared by homogenizing 1 g of cooked LM in 10 mL of 50 m*M* Tris, 10 m*M* EDTA, pH 8.3, for 20 s using a polytron on speed setting 4 (Brinkmann Instruments, Westbury, NY). Muscle homogenates (0.5 mL) were diluted 1:1 (vol/vol) with 2× protein denaturing buffer excluding mercaptoethanol and bromophenol blue (1× protein denaturing buffer consists of 2% SDS, 10% glycerol, 62.5 m*M* Tris, pH 6.8). Samples were heated to 50°C for 20 min, remixed and reheated 5 min, and then centrifuged at 22°C for 20 min at 16,000 × *g*. Protein concentrations were determined using the micro-BCA assay (Pierce, Rockford, IL). Samples were then diluted to contain 3 mg/mL of protein in protein denaturing buffer containing 10% mercaptoethanol and 0.008% bromophenol blue.

For electrophoresis, each lane was loaded with 15 μg of protein. Desmin was separated on 10% gels (37.5:1 ratio of acrylamide to bisacrylamide) with 4% (37.5:1) stacking gels. Discontinuous gels were run at 200 V for 45 min. Gels were transferred to Hybond-P Polyvinylidene Difluoride (Amersham, Arlington Heights, IL) membranes for 1 h at 4°C and 200 mA in buffer containing 25m*M* Tris, 193 m*M* glycine, and 10% methanol. Membranes were blocked with 2.5% sheep serum in Tris-buffered saline, pH 7.4, containing 0.05% Tween 20 (**TTBS**) for 60 min at room temperature, to prevent nonspecific antibody binding. Membranes were incubated with gentle shaking at room temperature for 60 min with a monoclonal anti-desmin diluted 1:100 (clone D3; developed by D. A. Fischman and obtained from the Developmental Studies Hybridomal Bank, Iowa City, IA). Membranes were washed 3 times (1 × 15 min; 2 × 5 min) with TTBS after each incubation. Bound primary antibodies were labeled for 60 min at room temperature with Immunopure goat anti-mouse IgG horseradish peroxidase conjugated secondary antibody diluted 1:10,000 (Pierce, Rockford, IL). Antibody binding was detected by incubating membranes for 5 min with SuperSignal West Dura Extended Duration Chemiluminescence substrate (Pierce). Membranes were exposed for 5 min with a ChemiImager 5500 digital imaging analysis system (Alpha Innotech, San Leandro, CA). A muscle specific at-death reference standard was run on each blot. Protein bands were quantified by using the ChemiImager 5500 digital imaging analysis system. The amount of desmin present was determined by measuring the density of the protein band on each blot compared with the at-death standard and calculating the percentage of desmin degraded.

Trained Sensory Panel

Trained sensory panels were conducted according to standards set by AMSA (1995). An 8-member trained sensory panel evaluated juiciness (1 = extremely dry; 8 = extremely juicy), tenderness (1 = extremely tough; 8 = extremely tender), meat texture (1 = extremely non-meat; 4 = meat-like texture), lamb flavor (1 = extremely bland; 8 = extremely intense), and off-flavor (1 = extreme off-flavor; 4 = no off-flavor) of LM and SM samples. Chops were cooked on an electric clamshell grill to 71°C internally. After cooking, chops were rested for 5 min to allow for the juices to redistribute. Chops were then cut into 2.5 cm × 1.3 cm samples using a sample sizing guide, placed into a Styrofoam bowl with holes in the bottom to allow juices to drain, covered with aluminum foil, and held in a warming oven at 60°C, until served. Samples were served to panelists in a randomized fashion, in private booths, under red lights to limit observation of visual differences.

Take-Home Consumer Panel

Panelists were identified through advertising in Brookings, South Dakota, newspapers and the retail sales room at the SDSU Meat Laboratory. To participate in this study, panelists needed to consume lamb at least twice per year. Chops were packaged and randomly assigned to a box (1 box per consumer); with each box containing a control and a BPT chop from both callipyge and normal lambs for a total of 4 chops per box. Chops were chosen from similar anatomical locations of the LM when boxed. Participating consumers picked up boxes from the SDSU Meat Laboratory between 6 and 21 d post-BPT enhancement (9 and 24 d postmortem) and were instructed to refrigerate chops until consumed. Consumers were given complete instructions, a demographic questionnaire, and a ballot to fill out before cooking, asking them to rate the following chop attributes using a 7-point hedonic scale (1 = extremely dislike; 7 = extremely like): like of portion size, like of color, like of leanness, and overall like of appearance. Consumers were allowed to cook chops to their preference as long as chop identification was maintained and approximate degree-of-doneness was recorded. After cooking, panelists evaluated and rated each sample for like of texture and tenderness, like of juiciness, like of flavor, and overall like of eating quality using a 7-point hedonic scale (1 = extremely dislike; 7 = extremely like). All ballots were to be returned by 22 d post-BPT enhancement to ensure timely consumption.

Statistical Analysis

Carcass data was analyzed using the PROC GLM procedure (SAS Inst. Inc., Cary, NC). Means were separated using the LSMEANS statement. Main effects in the model included phenotype and sex.

Ribeye area, LM sarcomere length, pH, cooking loss, shear force, cooked moisture retention, desmin degradation, and trained sensory panel attributes were analyzed using the PROC MIXED procedure of SAS with a split-plot design. Carcass was the whole plot and injection treatment (control vs. BPT) as the subplot. The random effect of animal within sex × phenotype served as the whole plot error term, and the residual served as the subplot error term. Means were generated using the LSMEANS statement and separated with the PDIFF option. Fixed main effects in the model included phenotype, sex, treatment, and their interactions (phenotype × sex, treatment × sex, treatment × phenotype, and phenotype × sex × treatment).

Semimembranosus and BF pH, cooking loss, shear force, and SM trained sensory panel attributes were analyzed using the PROC MIXED procedure of SAS. Means were generated using the LSMEANS statement and separated with the PDIFF option. Fixed main effects in the model included phenotype, sex, and treatment and their interactions (phenotype × sex, treatment × sex, treatment × phenotype, and phenotype × sex × treatment).

Take-home consumer panel data were analyzed using the PROC MIXED procedure of SAS. Chop was used as the experimental unit. Means were generated using the LSMEANS statement and separated with the PDIFF option. Fixed main effects in the model included phenotype, sex, treatment, and their interactions (phenotype × sex, treatment × sex, treatment × phenotype, and phenotype × sex × treatment).

RESULTS AND DISCUSSION

Carcass Measurements

Callipyge lambs had heavier BW and HCW, less adjusted backfat thickness, and decreased yield grades ($P < 0.05$, Table 1) compared with normal lambs. Unexpectedly, dressing percentage was not different between callipyge and normal lambs ($P > 0.05$). Previous reports indicated greater dressing percentages for callipyge carcasses (Koohmaraie et al., 1995; Jackson et al., 1997b). Increased dressing percentages have been attributed to lighter pelt weights and decreased viscera weights (Koohmaraie et al., 1995). Pelt and viscera weights were not measured in the present study. Conformation score of callipyge carcasses were greater ($P < 0.0001$) than normal carcasses. Carcass measurements did not differ ($P > 0.05$) between sexes (data not shown in tabular form).

Longissimus Traits

There was no difference in LM BPT injection percentage between sex ($P > 0.05$), but normal LM were injected to a greater percent (27.58%) than callipyge LM (22.05%, $P < 0.01$, data not shown in tabular form). This difference in BPT injection percentage may be due to callipyge LM having less water-holding capacity than normal LM. Clare et al. (1997) reported that when injecting a calcium chloride solution into normal and callipyge cuts, the purge was 2-fold greater in callipyge cuts. There was a significant phenotype × treatment interaction for LM pH ($P < 0.0001$, Table 2). For LM, BPT enhancement increased the pH of both normal and callipyge, but increased pH more for normal LM than callipyge LM ($P < 0.0001$). However, Nath (2006) reported that BPT enhancement increased muscle pH; however, the magnitude of change was dependent on injection percentage. Thus, the increased muscle pH by BPT enhancement is likely the result of a greater injection percentage for normal LM vs. callipyge LM.

Callipyge lambs had larger ribeye areas than normal lambs ($P < 0.0001$, Table 2), which was expected because muscle hypertrophy affects LM size in callipyge lambs (Carpenter et al., 1996). Ribeye area was increased by BPT enhancement when compared with control ($P < 0.0001$).

Table 1. Characteristics of normal and callipyge lambs

Trait	Normal	Callipyge	SEM	$P > F$
BW, kg	54.9	58.2	1.01	0.0276
HCW, kg	30.4	32.6	0.57	0.0116
Dressing percentage, %	55.5	56.0	0.83	0.6711
Body wall thickness, mm	24.8	23.1	0.81	0.1468
Adjusted fat thickness, mm	8.6	7.2	0.04	0.0275
USDA yield grade	3.8	3.2	0.18	0.0275
Conformation[1]	12.4	13.5	0.16	<0.0001
Maturity[2]	2.1	2.0	0.07	0.3240
Flank streakings[3]	355.5	368.5	8.47	0.2850
USDA quality grade[1]	12.5	12.7	0.12	0.2425

[1]10 = Choice$^-$, 11 = Choice^o, 12 = Choice$^+$, 13 = Prime$^-$, 14 = Prime^o.
[2]1 = A^0 to A^{33}, 2 = A^{34} to A^{67}, 3 = A^{68} to A^{100}, 4 = B^0 to B^{33}.
[3]100 = traces^0, 200 = slight^0, 300 = small^0, 400 = modest^0, 500 = moderate^0.

Normal LM had shorter sarcomeres than callipyge LM ($P < 0.0001$, Table 2). The shorter sarcomeres in normal LM when compared with callipyge LM may be attributed to the tendency of callipyge to have less total collagen content as well as less collagen crosslinking compared with normal (Field et al., 1996). Thus, if normal LM tended to have more collagen, it is possible that the normal LM chops could shrink more during cooking (reviewed by Tornberg, 2005) than the callipyge LM chops. In the current study, sarcomere length was measured on cooked samples and not on raw samples. Wheeler and Koohmaraie (1999) reported a correlation between raw and cooked sarcomere length of 0.97 and that cooked sarcomere length of normal lamb LM was 1.48 μm, which was similar to those reported in the present study. Studies investigating raw sarcomere length found no difference between normal and callipyge sarcomere length (Koohmaraie et al., 1995; Delgado et al., 2001; Kuber et al., 2003). No difference was found for sarcomere length between control and BPT, indicating that improved tenderness due to BPT enhancement was not a result of increased sarcomere length.

The phenotype × treatment interaction was significant for LM desmin degradation ($P < 0.001$, Table 2, Figure 1). For desmin degradation, BPT enhancement increased degradation in normal LM but decreased degradation in callipyge LM ($P < 0.001$). However, the magnitude of these treatment differences indicates that they are of little practical importance. Normal LM desmin degradation was similar to values reported by Veiseth et al. (2004) because normal LM desmin degradation was 94% at 360 h postmortem. Previous work by Koohmaraie et al. (1995), suggested that cytoskeletal proteins, including desmin, are degraded in both normal and callipyge lambs; however, degradation proceeds at a faster rate in normal lambs than callipyge lambs, a hypothesis supported by the present study.

No differences ($P > 0.05$) were found between phenotypes or treatments for LM cook loss, which paralleled results reported by Shackelford et al. (1997). The BPT-enhanced LM had greater cooked moisture retention compared with control LM ($P < 0.0001$, Table 2), which was similar to results by Nath (2006) who reported that BPT enhancement increased calculated moisture retention in beef LM. The increased muscle pH by BPT enhancement is due to the pH moving farther away from the isoelectric point, increasing the amount of bound water in the muscle and cooked product moisture retention.

As expected, LM WBS values were greater for callipyge than normal ($P < 0.0001$; Table 2) and similar to values reported by Shackelford et al. (1997) and Koohmaraie et al. (1998) for lamb LM at 7 d postmortem. Longissimus WBS values were improved by BPT enhancement when compared with control (3.38 vs. 6.23 kg, $P < 0.0001$). The improved WBS values from BPT enhancement may be attributed to increased muscle pH resulting in increased water-holding capacity retaining more moisture in the cooked product. Sheard and Tali (2004) reported that improved shear force values in cooked pork loin were a result of treatment with an alkaline solution, suggesting that the solution increased water content in the muscle and weakened myofibrillar structure. Yu and Lee (1986) reported that meat at pH 6.3 and above was more tender than meat at pH 5.8 to 6.3. Although BPT enhancement improved callipyge LM WBS from 8.63 kg to 5.27 kg, a mean WBS value of 5.27 kg is still above most of the thresholds that have been proposed between tender and tough such as 3.86 kg (Shackelford et al., 1991) and 4.0 kg (Miller et al., 2001).

SM and BF Traits

The BPT-enhancement injection percentage of SM was 27.8% for normal and 17.3% for callipyge, and BPT-enhancement injection percentage for BF was 30.0% for normal and 22.6% for callipyge (data not shown in tabular form). A phenotype × treatment interaction existed for pH in both SM and BF because BPT enhancement increased the pH of both treatments, but more for normal than for callipyge ($P < 0.01$, Table 3). Also, the phenotype × treatment interaction was significant for SM and BF percentage cook loss because BPT enhancement did not affect cook loss of normal SM and BF but BPT enhancement increased cook loss

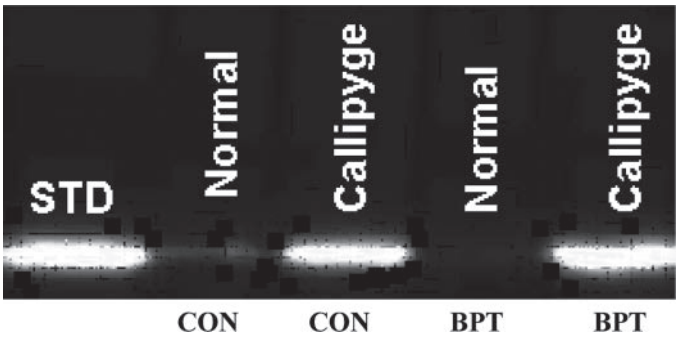

Figure 1. Representative Western blot for desmin from control (CON) and BPT-enhanced (BPI Processing Technology, Freezing Machines Inc., Dakota Dunes, SD) LM from normal and callipyge lambs. The BPT samples were injected with a solution containing water, ammonium hydroxide, carbon monoxide, and salt to a target injection of 20% over green weight. Desmin degradation was determined by measuring the density of the protein band compared with the at-death standard (STD).

of callipyge SM and BF ($P < 0.01$). A significant phenotype × treatment × sex interaction occurred for BF cook loss; however, interpretation of the interaction was nonsensical ($P < 0.05$, data not shown in tabular form) and likely resulted from the small number of observations per treatment combination.

A phenotype × treatment interaction was significant for SM WBS ($P < 0.05$, Table 3). For SM, BPT enhancement improved WBS in normal, but had no effect on WBS in callipyge ($P < 0.05$). Also, a significant phenotype × treatment interaction occurred for BF WBS ($P < 0.01$). For WBS, BPT enhancement improved values of normal and callipyge BF, but BPT enhancement improved WBS in callipyge BF to a greater extent than normal BF. Similar to findings by Shackelford et al. (1997), WBS values for the SM and BF muscles were affected by the callipyge phenotype, but not to the same extent as the LM. This reiterates that the callipyge phenotype affects the hypertrophy of several muscles and influences tenderness in proportion to the hypertrophy affect.

Longissimus Sensory Panel

Sensory juiciness scores were greater for normal LM than for callipyge LM ($P < 0.001$, Table 4), similar to results reported by Shackelford et al. (1997). The BPT-enhanced LM chops had greater sensory juiciness scores than normal LM chops ($P < 0.01$), which was expected as BPT-enhanced had a greater percentage of cooked moisture retention. The improved juiciness of the cooked LM may be a result of the meat pH farther away from its isoelectric point; thus, water-holding capacity was increased. A phenotype × treatment interaction was significant for sensory panel tenderness. The LM sensory tenderness ratings were improved by BPT enhancement for both phenotypes, but had a greater effect on callipyge than normal ($P < 0.05$). A phenotype × treatment × sex interaction ($P < 0.05$, data not shown in tabular form) was significant for tenderness ratings

Table 2. Least squares means of LM pH, ribeye area, cooked sarcomere length, cooked desmin degradation, cook loss, cooked moisture retention, and Warner-Bratzler shear force (WBS)

	Phenotype main effect				Treatment main effect				Phenotype × treatment interaction					
									Normal		Callipyge		Pooled	
Item	Normal	Callipyge	SEM	$P > F$	Control	BPT[1]	SEM	$P > F$	Control	BPT	Control	BPT	SEM	$P > F$
pH	6.4	6.1	0.06	<0.0001	5.9	6.6	0.07	<0.0001	5.9[a]	6.9[c]	5.9[a]	6.4[b]	0.08	<0.0001
Ribeye area, cm^2	17.3	21.8	0.44	<0.0001	18.3	20.8	0.34	<0.0001	15.8	18.7	20.8	22.9	0.47	0.1104
Cooked sarcomere length, mm	1.37	1.45	0.01	<0.0001	1.42	1.40	0.01	0.1231	1.39	1.35	1.46	1.44	0.06	0.3750
Cooked desmin degradation, %	92.18	37.69	4.60	<0.0001	65.46	64.41	3.33	0.4593	90.10[c]	94.26[d]	40.83[b]	34.56[a]	5.11	0.0007
Cook loss, %	18.04	17.36	0.70	0.4995	17.74	17.65	0.64	0.9143	18.04	18.03	17.45	17.28	1.23	0.9192
Cooked moisture retention, %	69.44	69.08	0.29	0.3952	65.90	72.62	0.28	<0.0001	65.77	73.11	66.03	72.14	0.56	0.1135
WBS, kg	2.7	7.0	0.38	<0.0001	6.2	3.4	0.30	<0.0001	3.8	1.5	8.6	5.3	3.81	0.0758

[a–d]Means for the phenotype × treatment interaction within a row lacking a common superscript letter differ ($P < 0.05$).

[1]BPT (BPI Processing Technology, Freezing Machines Inc., Dakota Dunes, SD) samples were injected with a solution containing water, ammonium hydroxide, carbon monoxide, and salt to a target injection of 20% over green weight.

Table 3. Least squares means of semimembranosus and biceps femoris pH, cook loss, and Warner-Bratzler shear force (WBS)

	Phenotype main effect				Treatment main effect				Phenotype × treatment interaction					
									Normal		Callipyge			
Item	Normal	Callipyge	Pooled SEM	$P > F$	Control	BPT[1]	Pooled SEM	$P > F$	Control	BPT	Control	BPT	Pooled SEM	$P > F$
Semimembranosus														
pH	6.2	5.9	0.04	<0.0001	5.8	6.3	0.04	<0.0001	5.9[a]	6.6[c]	5.8[a]	6.1[b]	0.07	0.0021
Cook loss, %	16.38	20.40	0.56	<0.0001	17.89	19.34	0.56	0.0698	17.30[ab]	16.36[a]	18.48[b]	22.33[c]	1.12	0.0034
WBS, kg	2.9	5.0	0.18	<0.0001	4.4	3.5	0.18	0.0004	3.7[b]	2.1[a]	5.1[c]	4.8[c]	0.36	0.0112
Biceps femoris														
pH	6.5	6.1	0.04	<0.0001	5.8	6.7	0.04	<0.0001	5.9[b]	7.1[d]	5.7[a]	6.4[c]	0.08	0.0008
Cook loss, %	15.93	21.17	0.56	<0.0001	16.79	20.31	0.57	<0.0001	15.11[a]	16.75[ab]	18.46[b]	23.88[c]	1.13	0.0212
WBS, kg	2.2	2.8	0.10	<0.0001	3.1	1.9	0.10	<0.0001	2.6[b]	1.7[a]	3.7[c]	2.0[a]	0.19	0.0028

[a–d]Means for the phenotype × treatment interaction within a row lacking a common superscript letter differ ($P < 0.05$).

[1]BPT (BPI Processing Technology, Freezing Machines Inc., Dakota Dunes, SD) samples were injected with a solution containing water, ammonium hydroxide, carbon monoxide, and salt to a target injection of 20% over green weight.

Table 4. Trained sensory panel ratings for LM

	Phenotype main effect				Treatment main effect				Phenotype × treatment interaction					
									Normal		Callipyge			
Trait	Normal	Callipyge	SEM	$P > F$	Control	BPT[1]	SEM	$P > F$	Control	BPT	Control	BPT	Pooled SEM	$P > F$
Juiciness[2]	5.60	4.98	0.11	0.0007	5.15	5.43	0.10	0.0069	5.45	5.75	4.84	5.11	0.18	0.9383
Tenderness[2]	6.50	4.99	0.14	<0.0001	5.10	6.39	0.11	<0.0001	5.96[b]	7.04[c]	4.24[a]	5.74[b]	0.20	0.0468
Meat texture[3]	3.35	3.84	0.06	<0.0001	3.91	3.28	0.06	<0.0001	3.85[bc]	2.85[a]	3.96[c]	3.71[b]	0.11	<0.0001
Lamb flavor[2]	4.80	4.74	0.08	0.6054	4.96	4.58	0.08	0.0004	5.18[c]	4.42[a]	4.74[b]	4.74[b]	0.15	0.0004
Off-flavor[3]	3.62	3.73	0.04	0.0288	3.71	3.63	0.03	0.0380	3.66	3.57	3.77	3.70	0.06	0.7975

[a–c]Means for the phenotype × treatment interaction within a row lacking a common superscript letter differ ($P < 0.05$).

[1]BPT (BPI Processing Technology, Freezing Machines Inc., Dakota Dunes, SD) samples were injected with a solution containing water, ammonium hydroxide, carbon monoxide, and salt to a target injection of 20% over green weight.

[2]Eight-point scale for juiciness, tenderness, and lamb flavor intensity: 1 = extremely dry, tough, and bland; 8 = extremely juicy, tender, and intense.

[3]Four-point scale for meat texture and off-flavor: 1 = extremely non-meat texture and extreme off-flavor; 4 = meat-like texture and no off-flavor.

of LM; BPT enhancement improved LM tenderness in callipyge ewes (5.78 vs. 4.11 kg) more than in callipyge wethers (5.71 vs. 4.38 kg) and in normal wethers (7.19 vs. 5.86 kg) more than in normal ewes (6.90 vs. 6.07 kg, $P < 0.05$) and likely resulted from the small number of observations per treatment combination. There was a magnitudinal phenotype × treatment interaction for meat texture sensory ratings ($P < 0.0001$). Meat texture ratings for BPT-enhanced LM decreased for both phenotypes, but affected normal LM chops more than callipyge LM chops ($P < 0.0001$). The decreased meat texture ratings for normal LM chops could be a result of a greater injection percentage (27.6 vs. 22.1%), which is closer to 30%. Nath (2006) reported decreased meat-like texture ratings for BPT-enhanced beef steaks to 30%. A phenotype × treatment interaction was significant for lamb flavor intensity because BPT enhancement reduced the lamb flavor intensity sensory ratings of normal LM chops, but did not affect ratings of callipyge LM chops ($P < 0.001$). Normal LM chops had slightly more off-flavors than callipyge LM chops ($P < 0.05$). The BPT-enhanced LM chops had more off-flavors than control LM chops ($P < 0.05$). Nath (2006) reported that beef steaks with greater BPT injection percentage had a greater incidence of off-flavors.

SM Sensory Panel

Normal SM chops rated greater than callipyge SM chops ($P < 0.0001$, Table 5) for juiciness sensory ratings, and BPT-enhanced SM chops had greater juiciness ratings than control SM chops ($P < 0.01$). There was a significant phenotype × treatment interaction for tenderness ratings of SM chops; BPT enhancement improved SM chop tenderness ratings for both phenotypes but improved tenderness ratings of SM chops from normal lambs more than tenderness ratings of SM chops from callipyge lambs ($P < 0.01$). A phenotype × treatment interaction was significant for meat texture ratings of SM chops; BPT enhancement reduced meat texture for normal SM chops, but did not affect meat texture of callipyge SM chops ($P < 0.0001$). For SM chops, BPT enhancement reduced lamb flavor intensity when compared with control SM chops ($P < 0.01$). No main effects or interaction were significant for SM chop off-flavor ratings ($P > 0.05$).

Take-Home Consumer Demographics

Demographics of the 119 consumer panelists are shown in Table 6. The majority of consumers were working full-time and earning an annual household income of over $40,000/yr. A similar proportion of male and female consumers participated. Most consumers (72.4%) consumed lamb often (at least once every 2 mo or more).

Cooking method and degree of doneness frequencies for the take-home consumer panel are shown in Table 7. Most consumers (65.5%) cooked the chops on a gas or

Table 5. Trained sensory panel ratings for semimembranosus muscle

	Phenotype main effect				Treatment main effect				Phenotype × treatment interaction					
									Normal			Callipyge		
Trait	Normal	Callipyge	SEM	$P > F$	Control	BPT[1]	Pooled SEM	$P > F$	Control	BPT	Control	BPT	Pooled SEM	$P > F$
Juiciness[2]	5.65	5.02	0.09	<0.0001	5.14	5.53	0.10	0.0045	5.36	5.94	4.92	5.12	0.19	0.1591
Tenderness[2]	6.13	4.34	0.13	<0.0001	4.47	5.99	0.13	<0.0001	5.11[b]	7.14[c]	3.83[a]	4.84[b]	0.26	0.0065
Meat texture[3]	3.34	3.86	0.06	<0.0001	3.91	3.29	0.06	<0.0001	3.88[b]	2.80[a]	3.95[b]	3.78[b]	0.12	<0.0001
Lamb flavor[2]	4.86	4.70	0.09	0.2226	4.96	4.60	0.09	0.0088	5.15	4.57	4.76	4.64	0.19	0.0827
Off-flavors[3]	3.59	3.69	0.04	0.0977	3.65	3.63	0.04	0.6835	3.60	3.57	3.70	3.68	0.09	0.9466

[a–c]Means for the phenotype × treatment interaction within a row lacking a common superscript letter differ ($P < 0.05$).

[1]BPT (BPI Processing Technology, Freezing Machines Inc., Dakota Dunes, SD) samples were injected with a solution containing water, ammonium hydroxide, carbon monoxide, and salt to a target injection of 20% over green weight.

[2]Eight-point scale for juiciness, tenderness, and lamb flavor intensity: 1 = extremely dry, tough, and bland; 8 = extremely juicy, tender, and intense.

[3]Four-point scale for meat texture and off-flavors: 1 = extremely non-meat texture and extreme off-flavor; 4 = meat-like texture and no off-flavor.

Table 6. Take-home consumer panel demographics

Item	Status	Frequency, %
Sex (n = 116)	Female	47.4
	Male	52.6
Age (n = 114)	18 to 29	14.3
	30 to 39	12.6
	40 to 49	21.9
	50 to 59	23.5
	60 to 69	14.3
	70 to 83	9.2
Working status (n = 115)	Not employed	31.3
	Part time	5.2
	Full time	54.8
	Student	8.7
Annual household income (n = 111)	Under $20,000	13.5
	$20,000 to $29,000	9
	$30,000 to $39,000	9.9
	$40,000 to $49,000	11.7
	$50,000 to $59,000	8.1
	$60,000 and above	47.8
Lamb consumption (n = 116)	Twice per year or less	27.6
	Once every 2 mo	31.9
	Once per month	24.1
	Once per week	13.8
	More than once per week	3.6

charcoal grill. The majority of consumers had an estimated degree of doneness for the chops of medium-rare, medium, or medium-well.

Take-Home Consumer Panel Raw and Eating Characteristics

Consumers rated "like of portion size" of callipyge LM chops greater than normal LM chops ($P < 0.0001$, Table 8) and BPT-enhanced LM chops greater than control LM chops ($P < 0.0001$). Sex affected portion size; consumers rated "like of portion size" greater for LM chops from wethers than LM chops from ewes ($P < 0.05$, data not shown in tabular form). Consumers rated "like of color" greater for callipyge LM chops than normal LM chops ($P < 0.05$) and pH-enhanced LM chops greater than control LM chops ($P < 0.0001$). The BPT-enhanced LM chops were brighter colored due to the presence of carbon monoxide in the brine solution. Consumers rated "like of leanness" of callipyge LM chops greater than normal LM chops ($P < 0.0001$). Mendenhall and Ercanbrack (1979) reported leanness is an important attribute when selecting lamb cuts. For "overall like of appearance," consumers rated callipyge LM chops greater than normal LM chops ($P < 0.0001$) and BPT-enhanced LM chops greater than control LM chops ($P < 0.01$). Overall, consumers liked larger, leaner, brighter-colored LM chops. These results correspond with Carpenter et al. (1997), who reported consumers, when given a choice, preferred the appearance of callipyge chops; 73% of consumers would purchase callipyge chops and only 26% were likely to purchase the normal chops.

Table 7. Cooking method and degree of doneness for take-home panel chops

Item	Frequency, %
Cooking method (n = 113)	
Gas grill	58.4
Charcoal grill	7.1
Electric grill	2.7
Oven broil	11.5
Pan fry	13.3
Oven-baked (roast)	3.2
Other	0.9
Degree of doneness (n = 112)	
Rare	1.8
Medium-rare	25.9
Medium	37.5
Medium-well	32.3
Well done	3.6

Take-home consumer panel palatability characteristics data are shown in Table 8. There was a significant phenotype × treatment interaction for "like of texture and tenderness." For LM chops, BPT enhancement improved "like of texture and tenderness" of both normal and callipyge, but improved "like of texture and tenderness" of callipyge LM chops more than normal LM chops ($P < 0.01$). Consumers rated "like of juiciness" greater for normal LM chops than callipyge LM chops ($P < 0.0001$) and BPT-enhanced LM chops greater than control LM chops ($P < 0.0001$). Consumers rated "like of flavor" greater for normal LM chops than callipyge LM chops ($P < 0.0001$) and BPT-enhanced LM chops greater than control LM chops ($P < 0.01$). A significant phenotype × treatment interaction occurred for "overall like of eating quality" ($P < 0.05$). For LM chops, BPT enhancement improved "overall like of eat-

Table 8. Longissimus take-home consumer panel raw and eating characteristic ratings

Trait	Phenotype main effect				Treatment main effect				Phenotype × treatment interaction					
									Normal		Callipyge			
	Normal	Callipyge	Pooled SEM	$P > F$	Control	BPT[1]	Pooled SEM	$P > F$	Control	BPT	Control	BPT	Pooled SEM	$P > F$
Raw characteristic[2]														
Like of portion size	4.21	5.25	0.09	<0.0001	4.41	5.04	0.09	<0.0001	3.87	4.55	4.95	5.54	0.19	0.7225
Like of color	5.09	5.33	0.08	0.0433	4.88	5.54	0.08	<0.0001	4.78	5.40	4.98	5.68	0.17	0.7587
Like of leanness	4.42	5.23	0.09	<0.0001	4.79	4.85	0.09	0.6466	4.41	4.43	5.18	5.27	0.18	0.7960
Overall like of appearance	4.62	5.37	0.08	<0.0001	4.84	5.15	0.08	0.0065	4.49	4.75	5.18	5.55	0.16	0.6046
Eating characteristic[2]														
Like of texture and tenderness	5.83	4.37	0.09	<0.0001	4.58	5.61	0.09	<0.0001	5.49[c]	6.17[d]	3.68[a]	5.06[b]	0.18	0.0074
Like of juiciness	5.76	4.73	0.09	<0.0001	4.88	5.61	0.09	<0.0001	5.51	6.01	4.25	5.22	0.17	0.0526
Like of flavor	5.61	4.89	0.09	<0.0001	5.07	5.43	0.09	0.0047	5.50	5.72	4.64	5.13	0.18	0.2946
Overall like of eating quality	5.66	4.54	0.09	<0.0001	4.74	5.46	0.09	<0.0001	5.46[c]	5.87[d]	4.03[a]	5.04[b]	0.18	0.0194

[a–d]Means for the phenotype × treatment interaction within a row lacking a common superscript letter differ ($P < 0.05$).
[1]BPT (BPI Processing Technology, Freezing Machines Inc., Dakota Dunes, SD) samples were injected with a solution containing water, ammonium hydroxide, carbon monoxide, and salt to a target injection of 20% over green weight.
[2]Seven-point scale: 1 = extremely dislike, 7 = extremely like.

ing quality" of both normal and callipyge, but improved ratings of callipyge LM chops more than normal LM chops ($P < 0.05$). Overall, BPT enhancement improved consumer palatability ratings of callipyge LM chops to levels near those of LM chops from normal lambs.

Improved tenderness and juiciness of normal and callipyge lamb by BPT enhancement was not due to altering sarcomere length or postmortem proteolysis but could be attributed to an increase in cooked moisture retention. Additional research is necessary to further elucidate the mechanism by which this technology improves meat quality attributes. Collectively these data support BPT enhancement as a means of improving consumer acceptability, both appearance and palatability, of normal and callipyge lamb.

LITERATURE CITED

AMSA. 1995. Research guidelines for cookery, sensory evaluation, and instrumental tenderness measurements of fresh meat. Am. Meat Sci. Assoc. and Natl. Livest. Meat Board, Chicago, IL.

Carpenter, C. E., O. D. Rice, N. E. Cockett, and G. D. Snowder. 1996. Histology and composition of muscles from normal and callipyge lambs. J. Anim. Sci. 74:388–393.

Carpenter, C. E., M. B. Solomon, G. D. Snowder, N. E. Cockett, and J. R. Busboom. 1997. Effects of electrical stimulation and conditioning, calcium chloride injection and aging on the acceptability of callipyge and normal lamb. Sheep Goat Res. 13:127–134.

Clare, T. L., S. P. Jackson, M. F. Miller, C. T. Elliott, and C. B. Ramsey. 1997. Improving tenderness of normal and callipyge lambs with calcium chloride. J. Anim. Sci. 75:377–385.

Cross, H. R., R. L. West, and T. R. Dutson. 1981. Comparison of methods for measuring sarcomere length in beef semitendinosus muscle. Meat Sci. 5:261–266.

Delgado, E. F., G. H. Geesink, J. A. Marchello, D. E. Goll, and M. Koohmaraie. 2001. The calpain system in three muscles of normal and callipyge sheep. J. Anim. Sci. 79:398–412.

Field, R. A., R. J. McCormick, D. R. Brown, F. C. Hinds, and G. D. Snowder. 1996. Collagen crosslinks in longissimus muscle from lambs expressing the *callipyge* gene. J. Anim. Sci. 74:2943–2947.

Hand, C. D., D. M. Wulf, and R. J. Maddock. 2005. Using pH-enhancement of beef steaks to improve consumer satisfaction. Page 523 in Proc. 51st Int. Congr. Meat Sci Technol., Baltimore, MD.

Jackson, S. P., R. D. Green, and M. F. Miller. 1997a. Phenotypic characterizations of Rambouillet sheep expressing the *callipyge* gene: I. Inheritance of the condition and production characteristics. J. Anim. Sci. 75:14–18.

Jackson, S. P., M. F. Miller, and R. D. Green. 1997b. Phenotypic characterizations of Rambouillet sheep expressing the *callipyge* gene: II. Carcass characteristics and retail yield. J. Anim. Sci. 75:125–132.

Kerth, C. R., T. L. Cain, S. P. Jackson, C. B. Ramsey, and M. F. Miller. 1999. Electrical stimulation on tenderness of five muscles from Hampshire × Rambouillet crossbred lambs with the callipyge phenotype. J. Anim. Sci. 77:2951–2955.

Koohmaraie, M., A. S. Babiker, A. L. Schroeder, R. A. Merkel, and T. R. Dutson. 1988. Acceleration of postmortem tenderization in ovine carcasses through activation of Ca^{2+}-dependent proteases. J. Food Sci. 53:1638–1641.

Koohmaraie, M., S. D. Shackelford, and T. L. Wheeler. 1998. Effect of prerigor freezing and postrigor calcium chloride injection on the tenderness of callipyge longissimus. J. Anim. Sci. 76:1427–1432.

Koohmaraie, M., S. D. Shackelford, T. L. Wheeler, S. M. Lonergan, and M. E. Doumit. 1995. A muscle hypertrophy condition in lamb (callipyge): Characterization of effects on muscle growth and meat quality traits. J. Anim. Sci. 73:3596–3607.

Koolmees, P. A., F. Korteknie, and F. J. M. Smulders. 1986. Accuracy and utility of sarcomere length assessment by laser diffraction. Food Microstruct. 5:71–76.

Kuber, P. S., S. K. Duckett, J. R. Busboom, G. D. Snowder, M. V. Dodson, J. L. Vierck, and J. F. Bailey. 2003. Measuring the effects of phenotype and mechanical restraint on proteolytic degradation and rigor shortening in callipyge lamb longissimus dorsi muscle during extended aging. Meat Sci. 63:325–331.

Leckie, R. K., J. R. Busboom, G. D. Snowder, S. K. Duckett, W. F. Hendrix, S. P. Jackson, J. D. Cronrath, M. Solomon, T. Mori, R. Sainz, A. Whipple, P. S. Kuber, N. M. Rathje, C. Carpenter, and N. E. Cockett. 1997. Investigating the efficacy of various procedures to improve tenderness of callipyge lamb. Proc. Recip. Meat Conf. 50:179. (Abstr.)

Mendenhall, V. T., and S. K. Ercanbrack. 1979. Influence of carcass weight, sex and breed on consumer acceptance of lamb. J. Food Sci. 44:1063–1066.

Miller, M. F., M. A. Carr, C. B. Ramsey, K. L. Crockett, and L. C. Hoover. 2001. Consumer thresholds for establishing the value of beef tenderness. J. Anim. Sci. 79:3062–3068.

Moore, S. W., R. A. Field, M. L. Riley, and W. C. Russell. 1998. Consumer evaluation of cuts from normal and callipyge lambs. Sheep Goat Res. J. 14:202–205.

Nath, T. 2006. Trained and consumer evaluations of five different beef muscles with or without pH enhancement using ammonium hydroxide. SDSU J. Undergrad. Res. 4:47–57.

Shackelford, S. D., J. B. Morgan, H. R. Cross, and J. W. Savell. 1991. Identification of threshold levels for Warner-Bratzler shear force in beef top loin steaks. J. Muscle Foods 2:289–296.

Shackelford, S. D., T. L. Wheeler, and M. Koohmaraie. 1997. Effect of callipyge phenotype and cooking method on tenderness of several major lamb muscles. J. Anim. Sci. 75:2100–2105.

Shanks, B. C., D. M. Wulf, and R. J. Maddock. 2002. Technical Note: The effect of freezing on Warner-Bratzler shear force values of beef Longissimus steaks across several postmortem aging periods. J. Anim. Sci. 80:2122–2125.

Sheard, P. R., and A. Tali. 2004. Injection of salt, tripolyphosphate and bicarbonate marinade solutions to improve the yield and tenderness of cooked pork loin. Meat Sci. 68:305–311.

Tornberg, E. 2005. Effects of heat on meat proteins—Implications on structure and quality of meat proteins. Meat Sci. 70:493–508.

USDA. 2001. Ammonium Hydroxide processing. http://www.ams.usda.gov/NOP/NationalList/TAPReviews/ammoniumhydroxide.pdf Accessed Mar. 14, 2007.

Veiseth, E., S. D. Shackelford, T. L. Wheeler, and M. Koohmaraie. 2004. Indicators of tenderization are detectable by 12 h postmortem in ovine longissimus. J. Anim. Sci. 82:1428–1436.

Wheeler, T. L., and M. Koohmaraie. 1999. The extent of proteolysis is independent of sarcomere length in lamb longissimus and psoas major. J. Anim. Sci. 77:2444–2451.

Wiegand, B. R., F. C. Parrish Jr., D. G. Morrical, and E. Huff-Lonergan. 2001. Feeding high levels of vitamin D_3 does not improve tenderness of callipyge lamb loin chops. J. Anim. Sci. 79:2086–2091.

Yu, L. P., and Y. B. Lee. 1986. Effects of postmortem pH and temperature on bovine muscle structure and meat tenderness. J. Food Sci. 51:774–780.